Design of a Polyphase Alternator

Millard Gilmore

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THE DESIGN OF A POLYPHASE ALTERNATOR

A THESIS

PRESENTED BY

MILLARD GILMORE

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

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THE DESIGN OF A POLYPHASE ALTERNATOR.

The object of this thesis is to bring forth an easy and efficient method of alternator design for machines of this capacity.

More factors enter in to complicate matters than in direct current designs. The effect of leading and lagging currents, wave forms of magnetization and e.m.f. have to be considered as well as the inductance of the armature slots and armature coils. The frequency which is to be obtained determines the speed to a great extent. The phase relations of the e.m.f.s will determine the output as well as the power factor of the load on which the machine is to operate.

In designing the machine some definite speed is first decided upon. This fixes the number of poles required and limits to a great extent the size of the armature that can be used.

The method of proceedure is to fix upon some definite number of ampere turns per inch of periphery of the armature surface and from this work out the design (preliminary). If it is found that the diameter of the armature is such that the losses are too great, that the rise of temperature is too small or too great, or that the peripheral speed is excessive, it must be changed and a new set of calculations made. This must be continued until the armature that overcomes all these conditions success-

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fully is found. It is well to make out a table and make calculations for each diameter on the same sheet for comparison. In order that the best armature for the purpose may be obtained, it is necessary to design a number of them, the preliminary calculations for each diameter being made. The following will indicate the method used:-

It is desired to design an alternator of fifty kilo-watts capacity having the following specifications:

--* SPECIFICATIONS *--

Output	50 K.W.
Number of phases	3
Voltage	2300
Frequency	60
Type	Belted.
Revolving part	Fields.

The speeds usually chosen for alternators of this capacity are 900 and 1200 r.p.m. The former requires eight poles and the latter six poles in order that 60 cycles may be obtained.

The diameter of the armature for this output should be between 16" and 29", 20" as an average. The air gap selected will be 3/16".

In selecting the proper diameter of armature a table was made out with columns headed 16", 18",20", and 22" armatures. The calculations were carried through for each of these diameters and the 18" armature was selected.

The calculations (preliminary) for this size follows:

The diameter of the field will be

$$(18 - 2 \times 3/16) = 17\text{-}5/8''$$

Therefore the peripheral velocity $= 1200 \times \pi \times 17\text{-}5/8$

$= 5540$ ft./sec.

Below follows the preliminary design, which is self explanitory.

--* PRELIMINARY DESIGN *--

Diameter of armature, (D),	18"
Air gap, (ag),	3/16"
Diameter of fields,	17-5/8"
Peripheral velocity, ft./sec. $= \pi D \times 1200 =$	5540
Pole pitch, (p.p.) $= \pi D/6 =$	9.43"
Polar arc, (p,a,) = .635 x p.p. =	6"
Current per phase, $I/ph. = \frac{50 \times 1000}{2300 \times \sqrt{3}} =$	12.56
Ampere turns per in. of circumference,	220
Ampere turns, total, $= \pi D \times NI/in.$	12450
Ampere turns per ph., NI/ph. =	4150
Turns per phase, N/ph. = 4150/12.56 =	330
Turns per phase per pole, = 330/6 =	55
Slots per pole per phase =	2
Conductors per slot, = 55 x 2 / 2 =	55
K, the assumed form factor,	1.113
Flux per pole = ϕ	
$\phi = \frac{E \times 10^8 \times 1 \times 60}{1200 \times \sqrt{3} \times 1.11 \times 6 \times 660} =$	1,500,000
Density in pole pieces, lines/sq.in.	44,000
Circular mils per ampere in arm. cond.	600

Length of pole axially,	6"
Size of armature conductor,	7536
Use wire B & S gauge,	#11
Length of one turn,	45"
Total length of one phase = 45/12 x 330 =	1238'
Resistance per phase at 60° C. =1.46x1238=	1.81
IR drop at full load= $\sqrt{3}$ x 12.56 x 1.81 =	39.4
Per cent IR drop = 39.4/2300 =	1.71
I^2R loss =$(12.56)^2$x 1.81 x 3 = 860 =	1.72 %

--* CORE *--

Density in armature core in Gauses,	5000
Depth of core,	4.1
Total volume of armature = (29.7^2- 18^2).785 x 5.67 =	2530
Volume of slots = 1-3/4x3/4x36x5.67=	268
Volume of core in cu. in.	2262
Weight of core = .28 x 2262 =	$635^{\#}$
Cycles x Kilogrammes = 5 x 60 =	300
Core loss = 1.8 x 635 =	1142
Total losses = 860 + 1142 =	2002

--* RADIATION CALCULATIONS *--

Area of inner surface of armature, S_1,	382
" " outer " " " S_2,	630
" " end connections of armature coils, S_3,	2160
Area of end of armature and ventilating ducts, S_4,	2552

$S_1 = 18 \times \pi \times 6.75$

$S_2 = 29.7 \times \pi \times 6.75$

$S_3 = (.5 \times 1.375)\ 2 \times 36 \times 116$

$S_4 = 4\text{-}1/2(.785)(29.7^2 - 18^2)$

- NOTES -

In calculating S_4 it is assumed that the area of one of the ventilating ducts equals the area of one end. Since there are three ventilating ducts of 1/4", 1/8", and 1/8" width and the width of two is small it is assumed that the combined areas of the two 1/8" ducts equals only 1-1/2 times the area of one end.

--* RADIATION COEFFICIENTS *--

These were obtained from Esterlines Design of Electric Machinery, Vol.I, p 219.

$K_1 = .0227$ watts radiated per degree C. rise.

$K_2 = .0090$ " " " " " "

$K_3 = .0226$ " " " " " "

$K_4 = .0090$ " " " " " "

Then - **TEMPERATURE RISE**

$K_1S_1 = .0227 \times 382 =$ 8.675

$K_2S_2 = .0090 \times 630 =$ 5.66

$K_3S_3 = .0226 \times 2160 =$ 48.90

$K_4S_4 = .0090 \times 2552 =$ 21.98

Total - 85.215

Temperature rise = 2002 ÷ 85.215 = 23.5°C. by thermom.

= 23.5 x 1.25 = 29.4 C. by resistance.

The core loss was obtained from a curve given in Esterline, which gives the loss directly when the frequency and density are known. This loss was checked up by the more laborious method of finding the eddy current losses in the teeth and core and the hysteretic losses for the same and adding them. This checked very closely with the value obtained from the curve; in fact the combined eddy current and hysteretic losses for the teeth and core by calculation was 1092 watts while the losses as obtained from the curve was 1142 watts. It is thus seen that this method is very much more rapid and fairly accurate. The error is on the right side.

The radiation calculations were also made with the help of a table given in Esterline, which gives the coefficients to be assumed at different velocities of the moving parts. The fanning action of the rotating fields is assumed to cause the armature to radiate as much heat over its inner surface as if it were moving. The end connections of the coils on the armature will dissipate the major portion of the heat. They are assumed to be moving. The outer surface of the armature will dissipate part of the heat. The ends and ventilating ducts are each assumed to dissipate an equal amount. The latter surfaces, i.e., the outer and end surfaces of the armature and ventilating ducts are assumed to be stationary. The coefficient for a stationary surface is .009 watts per sq. in. per degree C. rise.

The core loss has been kept down very low by putting

the density down to a low figure. This will give a good efficiency on low power factors.

Now, since we have obtained an armature which will operate successfully the rest of the design may be proceeded with. The first thing to do is to design the pole pieces so that a sinusoidal e.m.f. wave may be produced. The best way to do this is to assume an e.m.f. sine wave and work back from that to determine the magnetization wave necessary to produce this sine wave. After the wave has been formed, the pole face must be shaped to give the desired form of wave. This is the reverse of the method employed by Esterline, S. P. Thompson, and others. The method that they use is to assume a pole face and work for the form of e.m.f. wave that this will produce. If this wave is not of the desired shape the pole face is altered and the calculations made over again.

On the accompanying curve sheet is shown the e.m.f. wave which it is desired to obtain. This is a sine curve. The curve marked B is the curve actually obtained, which approximates very closely to a sine wave. If the ordinates are measured off, the value of the e,m.f. nacessary at each point is obtained. Then this value is divided by two, since each half of a coil will produce one half of the e.m.f. and a value apportioned to each element that goes to produce the e.m.f. so that the sum amounts to one half of the value obtained from the curve. In order that this method may be better understoodnthe calculations and results are calculated, tabulated, and explained below.

The winding used for this machine is a concentric loop winding having two coils per pair of poles. The spread of the inner coil is less than, and the outer coil is greater than the pole pitch, so that the sum is equal to the pole pitch. Each slot may be considered in this case to contain a single element since theee.m.f.s of all the conductors in the slots are approximately in phase.

On the curve sheet conductors marked A_1A and B_1B constitute one winding. The center of the coil is at 10. Now the e.m.f. which is to be developed with the coils in this position is the height of the ordinate at 10. The element A is shown to be cutting the maximum flux, while A_1 is not, hence the value of the flux wave at A_1 is

$$(E/2 + (X + E/2))\ 1/2$$

where E = the maximumordinate of the e.m.f. wave.

X = the ordinate over the center of the coil in this case it is ordinate 10.

Proceeding in this manner we can calculate the magnetization wave for any winding. Below are the results obtained:

DATA FROM E.M.F. WAVE.

Pos. of coil.-	e.m.f. Developed.	A_1.	A_2.	B.	B_1.
0	00	- 6	6	- 6	6
1	58	- 3.2	32	- 3	32
2	106	0	53	0	53
3	144	3	69	3	69
4	186	15	78	15	78
5	244	32	90	32	90
6	306	53	100	53	100
7	338	69	100	69	100
8	356	78	100	78	100
9	380	90	100	90	100
10	400	100	100	100	100
11	400	100	100	100	100
12	400	100	100	100	100

Now we can construct the flux wave, since we have the components which are necessary to produce the e.m.f. wave. In this case we can take the values of one component and plot them which will give the wave form of the flux since the maximum ordinate is taken as 1 or 100 %. Following this method we tabulate results below.

DEDUCTION OF FLUX WAVE AND

DETERMINATION OF POLE SHAPE.

Point.	% Ordinate of Flux wave.	Fringe of ajac.wave.mid.	% of gap.	Reciprocal.	length across air gap.m.m.
12	100	negligible.	100	.2	5.
11	100	"	100	.2	5.
10	100	"	100	.2	5.
9	100	"	100	.2	5.
8	100	"	100	.2	5.
7	90	"	90	.180	5.55
6	78	"	78	.156	6.32
5	69	1.27	70.27	.141	7.10
4	53	1.83	54.83	.111	9.00
3	32	2.38	34.38	.0714	14.0
2	15	3.6	18.6	.0192	52.0
1	3	4.2	7.2	.0144	66.0
0	0	5.3	5.3	.0106	75.0
- 1	3	7.2	4.2	.0084	83.3
- 2	15	18.6	3.6	.0072	92.8
- 3	32	34.38	2.38	.00476	100.8
- 4	53	54.83	1.83	.00366	109.4
- 5	69	70.27	1.27	.00255	117.5

The air gap in this case was 5 m.m. but may be assumed any figure provided the parts are drawn to scale. The method of laying off these points is to divide the pole pitch into an equal number of parts while the surface of the pole is divided into a like number of equal parts. The points on the armature surface must be the same dis-

tance apart as those on the pole surface. There are four general methods of calculating the flux tending to enter the armature at each point. One method described by Esterline and due to Goldsbourough, is to take the distance to all points on the pole from each point on the armature, find the reciprocals and add them, having multiplied the rwciprocals of the distances to points under the field coils by the assumed magnetomotive force at that point. This m.m.f. is assumed to be zero at the base of the pole and a maximum at the top of the coil. Hence a point under th the center of the coil would have a m.m.f. of .5 of the maximum. The pole face is assumed to be an equal potential plane.

This method is very long and tedious and is not any more accurate than others which are much simpler and easier.

S. P. Thompson describes three methods. The first is to lay out the armature surface and the pole surface to scale. They are divided into equal parts as before, and the distances to corresponding points taken. The reciprocals of these distances give the flux tending to enter at each point. Of course these lines must not be drawn in straight but must be drawn according to the path which the flux will take. In this the error lies in assuming a flux path. A way to get at this is to cut the pole piece and armature surface out of a piece of wrot iron sheeting; then to magnetize the pole and scatter filings in the gap. The positions taken by the filings will indicate the flux paths. This method was used in thesez calculations tb check the assumed path.

Another method which does not appear very reliable is to draw in a line from the pole tip at some angle with the pole, say from the tip to the root of the adjacent pole and divide this line into distances as used on the armature surface as before. The reciprocals of the straight line distances to corresponding points will determine the flux at each point on the armature.

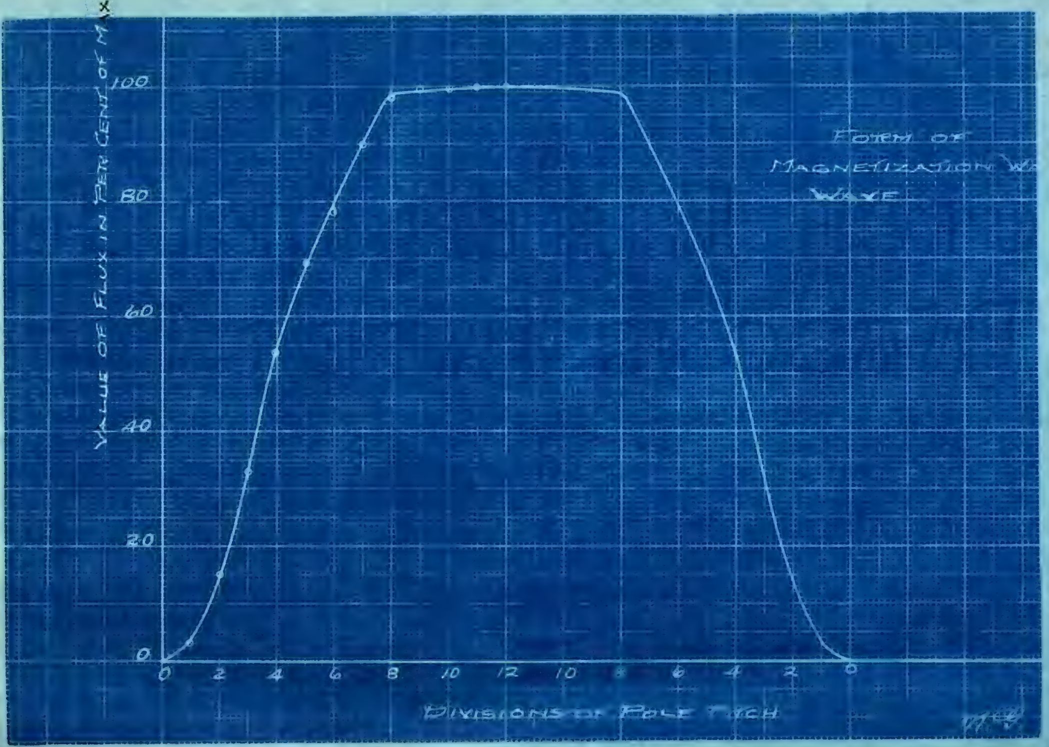
The flux wave that gave the approximate sine wave of e.m.f, having been obtained the next thing to determine is the power factor. This is shown on the next page. The wave is divided into a number of equal parts and the average ordinate of each part found,(assumed to be the middle ordinate: then the ordinates are each squared and the sum of all found. The square root of the mean square is the effective e.m.f. developed while the average e.m.f. is the average e.m.f. developed. The form factor comes out to be 1.119 which shows that the wave is very near that of a sine wave.

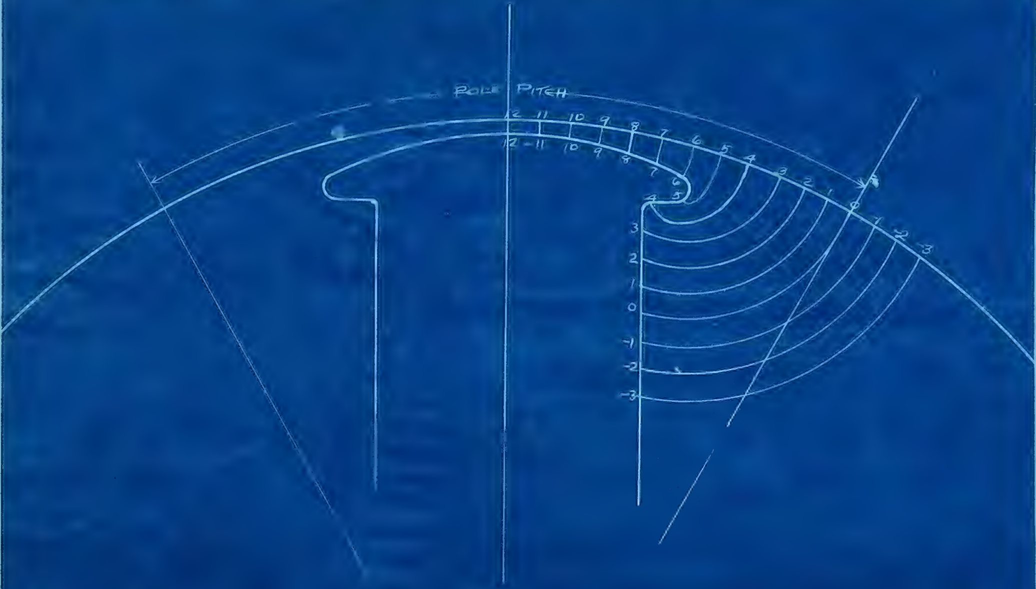
In order to determine the direct current e.m.f. that would be generated, we assume that the elements cutting the flux are distributed along the pitch in as many parts as we assumed the wave to be divided into. Then it is assumed that all sweep across so as to cut the entire flux in one second. The formula for the e.m.f. developed is

$$E = \frac{n\ c\ p\ \phi}{b}$$

where, n = the rate of passage of conductors,

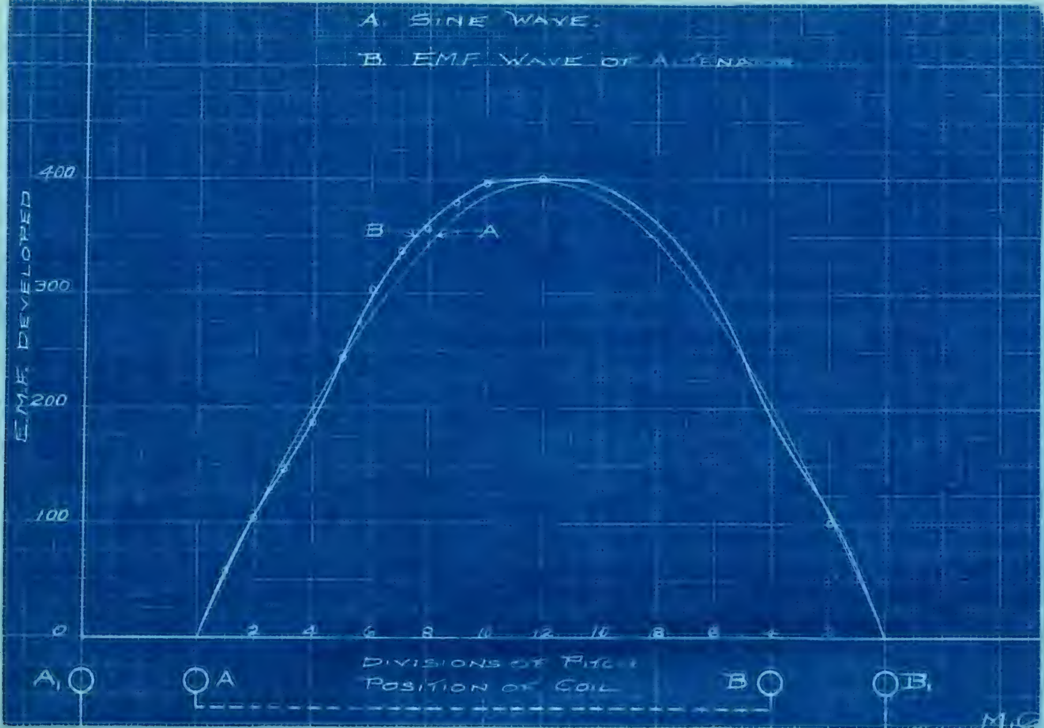
c = the number of divisions of the pitch filled with alternating current conductors,


FORM OF
MAGNETIZATION WA
WAVE
VALUE OF FLUX IN PER CENT OF MAX
0
20
40
60
80
100
0
2
4
6
8
10
12
10
8
6
4
2
0
DIVISIONS OF POLE PITCH



METHOD OF OBTAINING FLUX DISTRIBUTION IN AIR GAP

9. 8.


A. SINE WAVE.
B. EMF WAVE OF ALTERNA
E.M.F. DEVELOPED
0
100
200
300
400
B
A
2
4
6
8
10
12
10
8
6
4
2
DIVISIONS OF PITCH
POSITION OF COIL
A1
A
B
B1
M.C

DETERMINATION OF THE FORM FACTOR.

Ordinate #.	Value.	Squares.
1	30	900
2	80	6400
3	135	18226
4	170	28900
5	215	46225
6	280	78400
7	320	102400
8	350	122500
9	370	136900
10	390	152100
11	400	160000
12	400	160000
13	390	152100
14	370	136900
15	350	122500
16	320	102400
17	280	78400
18	215	46225
19	170	28900
20	135	18225
21	80	6400
22	30	900
Total -	5480	1706900
Mean -	249	77586

$$\sqrt{\text{mean}^2} = 278.5$$

Therefore the form factor = 278.5 / 249 = 1.119

p = the number of poles,

ϕ = the flux in one pole.

Then,

$$n = 1 / (2 \times 24) = 1 / 48$$

$$b = 1 \qquad p = 2$$

$c = 4$ $\qquad \phi = 1590$ = the average ordinate of the flux wave.

Then,

$$E = \frac{1 \times 2 \times 1590 \times 4}{48 \times 1} = 265$$

Therefore, $\quad K = 278.5 / 265 = 1.09$

This K corresponds so nearly to the K that we assumed that no alteration meed be made for it.

The saturation curve was determined next. This curve is determined by finding the ampere turns required for the various parts of the magnetic circuit and the voltage of the machine for each of the assumed number of ampere turns. The calculations for this curve are shown on the following page. The ampere turns for the yoke are negligible since the length is very small.

EXPLANATION OF THE SYMBOLS USED ON THE FOLLOWING PAGES.

B_t = assumed densities in top of teeth.

B_r = the corresponding densities in the bottom of the teeth.

H_t = the value of H (= B / u) at top of teeth.

H_r = " " " " " " bottom of teeth.

H_{av} = average density = $(H_r + H_t)/2$

$B_t \frac{x}{z} + H_t \frac{y}{z}$ = the average uncorrected density per sq. centimeter of armature surface = B' ag.

$$Bag = B'ag \frac{L'}{L}$$

L' = the net length of armature core,

L = gross " " " "

$(Si)_{ts}$= ampere turns for teeth and slots,

$(Si)_{ag}$ = " " "air gap,

Bc = the corresponding density in the armature core,

H_c = value of H for core,

$(Si)_c$= the ampere turns required for the core,

B_p= the corresponding density in the pole core having taken account of leakage.

H_p= H for the pole.

Si $(Si)_p$= ampere turns for the pole,

(Si) = sum of ampere turns for teeth and slots, air gap, armature core, and pole.

M = maxwells per pole = Bag x air gap area in cms.

E_o= open circuit e.m.f. as determined by the alternator equation = $\frac{n\ c\ p\ \phi\ \ K}{10^8\ \ b}$

L = width of slot,

x = width of tooth at armature surface,

z = pitch of tooth.

The inductance of the slots was calculated by a formula given in Esterline. The inductance of two slots was calculated first by finding the reluctance of the slots, then the flux set up by the conductors in the slots,

DATA FOR CALCULATED SATURATION CURVE.

B_t.	H_t.	B_r.	H_r.	H_{av}.	$H_t\frac{y}{z}$.	$B_t\frac{x}{z}$.	B'ag.
2000	2.0	1785	1.8	1.9	.758	1240	1241
4000	2.2	3570	2.05	2.12	.834	2480	2481
6000	2.8	5550	2.6	2.7	1.03	3724	3725
8000	3.2	7140	3.0	3.1	1.21	4965	4966
10000	4.0	8925	3.4	3.7	1.51	6205	6206
12000	7.0	10700	4.0	5.5	2.64	7450	7453
14000	12.1	12500	7.0	9.55	4.58	8700	8705
15000	18.3	13400	11.2	14.75	5.92	9320	9326
16000	31.2	14300	15.2	23.4	11.4	9940	9951

L = .5" = width of slot,

z = 1.32" = slot pitch at armature surface,

x = .82" = width of tooth at surface.

Bag.	$(Si)_{ts}$.	$(Si)_{ag}$.	B_c.	H_c.	$(Si)_c$.	B_p.	H_p.
1083	6.72	410	875	1.75	31.8	2100	2.
2165	7.50	819	1810	1.80	32.8	4330	2.4
3250	9.55	1230	2720	2.10	38.2	6500	3.
4340	11.00	1640	3500	2.25	41.0	8680	3.8
5330	13.1	2020	4370	2.40	43.6	10660	4.3
6510	19.5	2460	5240	2.60	47.3	13020	8.375
7600	33.8	2870	6125	2.80	51.0	15200	30.5
8140	52.3	3080	6560	3.00	54.5	16280	57.5
8700	83.0	3290	7000	3.10	56.4	17400	128.5

$(Si)_p$.	Total Si.	Useful flux.	e.m.f.
28.2	472.7	253000	438
33.8	883.1	506000	876
42.3	1320.0	760000	1313
53.5	1745.0	1010000	1750
60.6	2138.0	1265000	2190
118.0	2538.6	1520000	2630
430.0	3384.8	1770000	3067
810.5	3977.3	1895000	3286
1815.0	5246.4	2030000	3510

and then the inductance of these was obtained.

For two uncovered slots the reluctance

$$R_2 = 1 / (A / 4F + B / 2E + C / \pi D) \; L$$

A = depth of coil in slot,

B = depth of slot above coil,

C = width of tooth (top).

L_a = net length of armature in cms.

D = pitch of teeth,

E = width of slot (top),

F = width of slot (bottom).

In this case,

$A = 4.125$ $D = 3.35$ $L_a = 14.8$

$B = .952$ $E = 1.27$ $L_e = 40.6$

$C = 2.08$ $F = 1.27$ $G = 2.33$

L_e = length of end connections in cms.

G = width of tooth at root.

Then,

$$R_2 = \frac{1}{\left[\frac{4.125}{4 \times 1.27} + \frac{.952}{2 \times 1.27} + \frac{2.08}{3.14 \times 3.35} \right] 14.8}$$

$$= .0645 \text{ oersted.}$$

Then,

$$\phi_2 = 2 \times 55(1.257/.0645 + .4 \times 40.6)$$

$$= 3932 \text{ maxwells.}$$

Therefore,

$$L = 2 \times 55 \times 3932 / 10^8 = .00435 \text{ Henry.}$$

For the two covered slots we obtain,

$$R_2 = \frac{1}{\left[\frac{4.125}{4 \times 1.27} + \frac{.952}{2 \times 1.27} + \frac{2.08 + 3.35}{4 \times .447}\right] 14.8}$$

$$= .01688 \text{ oersted.}$$

$$\phi_2 = 2 \times 55(1.257/.01688 + .4 \times 40.6)$$

$$= 9981.4 \text{ maxwells.}$$

$$L_2 = 2 \times 55 \times 9981.4 \,/\, 10^8 = 0.01098 \text{ Henry.}$$

Then the local inductance (average) for one group is one half of the sum of the two which is:

$$L_{av} = \frac{.004325 - .01098}{2} = .007652 \text{ Henry.}$$

Since there are six coils per phase, the inductance per phase is,

$$L_{ph} = .007652 \times 6 = .0459 \text{ Henry.}$$

The local reactance drop is then,

$$C_a = 2\pi \times 60 \times .0459 \times 12.56 = 218 \text{ volts.}$$

Then $\tan \phi = \dfrac{218}{(2300/\sqrt{3}) + 22.8} = .1612$

Or, $\phi = 9^\circ \; 10'$

DETERMINATION OF FIELD INDUCTANCE.

The maxwells per pole at 2300 volts is 1500000, which divided by the ampere turns necessary to produce this gives

$$\phi' = \frac{1,500,000}{2250} = 666 \text{ maxwells per ampere turn.}$$

The flux linked with 55 turns is,

$$55 \times 666 = 36,300 \text{ maxwells.}$$

Then the field inductance is,

$$36,300 \times 55 / 10^8 = .01990 \text{ Henry.}$$

And the average is,

$$L_{av} = .01990 / 2 = .00995 \text{ Henry.}$$

Then the total per phase is,

$$L_{ph} = .00995 \times 6 = .0596 \text{ Henry.}$$

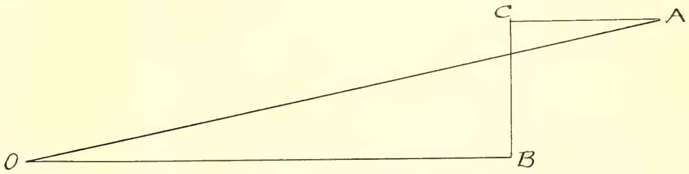
The reactive drop of the field inductance is,

$$E_f = 2\pi \times 60 \times .0596 \times 12.56 \times .159 = 44.75 \text{ volts.}$$

The total reactance drop is then,

$$218 + 44.75 = 263 \text{ volts.}$$

Then by the diagram below the full load voltage developed is OA.



In this AC is the resistance drop, BC the reactance drop, and OB the terminal voltage.

Then,

$$OA = \sqrt{(2300 + 39.4)^2 + (455)^2}$$

$$= 2382 \text{ volts.}$$

The armature demagnetizing turns are , Nd,

N_d = 1/2 x .71 x I_{ph} (sin ϕ x no. phases x no. turns per pole x leakage coefficient x factor depending on spread of coil).

Or, N_d= 1/2 x .71 x I (sin ϕ x N_p x V x k)

= 1/2 x .71 x 12.56(.27 x 55 x 3 x 1.25 x 1.11)

= 275

The ampere turns required to give 2392 volts as obtained from the saturation curve is 2300, adding the demagnetizing turns we have 2575 as the ampere turns required at full load. Referring to the saturation curve, we find that this produces approximately 2600 volts on no load. The per cent regulation then is,

$$\frac{\text{no load voltage - full load voltage}}{\text{full load voltage}}$$

$$= \frac{2600 - 2300}{2300} = 13 \%$$

This is not very bad for small machines.

It is naxt necessary to obtain the dimensions of the field winding. Ten amperes will be used for excitation, then the number of turns per pole will be 2575/10 = 257.5 Assuming 650 circular mils per ampere we have 6500 circular mils as the area of conductor, which corresponds to # 12 B &S gauge.

Length of mean turn = 25"

Length of total turns = 536'

The resistance at 60°C = 1.846 ohms / 1000ft.

Therefore the resistance per coil = 536 / 1000 x 1.846

= .99 ohms.

For 6 coils resistance = 6 x 99 = 5.94 ohms.

Then drop over fields at full excitation = 5.94 x 10

= 59.4 volts.

With an exciter voltage of 120 this is 59.4 / 120

= 49.5 %.

ALTERNATOR CALCULATIONS.

# phases,	3
Rated capacity at full load, K.W.	50
Machine voltage,	2300
Frequency, cycles per sec.	60
Type,	Belted.
Revolving part,	Fields.

- Materials -

Armature core,	Steel stampings.
Pole shoe,	" "
Field yoke,	" "
Frame,	Cast iron.
Shaft,	Steel.
Field spider,	"
Bearings,	Brass.

Density in lines per sq.in.	No Load.	Full Load.
Air gap,	45,000	46,000
Armature core,	32,200	33,000
Armature teeth (top),	66,000	77,000
Armature teeth (bottom),	59,000	69,000
Field core,	61,200	84,000
Yoke,	29,200	39,300

- ARMATURE -

Peripheral vel. of revolvong part,	5540 '/min.
Air gap, inches,	3/16"
Diameter of armature,	18"

Current per phase,	12.56 amp.
Circuits per phase,	1
Armature ampere turns per pole per phase,	692
" " " " inch of circum.,	220
" turns per phase,	330
No, of slots per pole per phase,	2
Width of tooth at armature surface,	13/16"
Width of tooth at root,	15/16"
Width of slot,	3/4"
Depth of slot,	1-3/4"
Depth of core below teeth,	4-1/8"
No. of ventilating ducts,	3
Width of each duct, inches,	1/4,1/8,1/8.
Length of armature core over all,	6.75"
Effective length of armature core, magnetic iron,	5.67"
Ratio, effective to gross length,	1.19

- FIELD -

Diameter at pole face,	17-5/8"
Pole pitch, inches,	9.43"
Per cent of armature surface covered by poles,	63.5
Polar arc, inches,	6"
Length of pole face, axially,	6"
No. of ventilating ducts,	0
Net length of pole face,	5.67"
Area of pole face, sq.in.	34
Air gap density, lines per sq.in.,	45,000

Flux per pole, maxwells,	1,500,000
Leakage coefficient,	1.25
Density in pole core, no load, lines/sq.in.,	61,200
Area of pole core, sq.in.,	21.25
Width of pole core (along shaft), inches (net),	5.67
Thickness of pole core, inches,	3.75
Radial length of pole, inches,	4

- YOKE -

Diameter of yoke, outside, inches,	9-5/8
Depth of yoke, inches,	3-5/16
Length of yoke, inches,	6

- WAVE FORM -

See accompanying curve sheet.

$$\text{Form factor} = K = \frac{\text{effective A.C. e.m.f.}}{\text{D.C. E.m.f.}} = 1.09$$

- ARMATURE CORE LOSS -

Depth of core below slots,	4-1/8"
Depth of slots, inches,	1.75
Net length of armature core, inches,	5.67
Net volume of arm. core, cu.in.,	2262
Weight per cu.in., lbs.,	.28
Net weight of armature core, #,	635
Pounds per K.W.,	12.7
Density in armature core, lines/sq.in.,	32,200
Frequency of machine, cycles/sec.,	60

Frequency x kilogausses,	300
Loss per lb. of armature core (watts),	1.8
Per cent core loss of output = 1142/50000	2.3

- ARMATURE WINDING -

Armature current per phase,	12.56 amp.
No. of circuits in parallel per phase,	1
Connection of winding,	Star.
Mean length of one turn of arm. coil,	45"
No. of turns per coil,	55
No. coils per phase,	6
Length of conductor per phase,	1238'
Circular mils per ampere,	650
Area of armature conductor, circ. mils,	7536
Wire gauge, B & S,	#11
Resistance of armature per phase, 60°C, ohms,	1.81
Volts drop in armature per phase,	39.4
I^2R loss in armature per phase, watts,	287
Total I^2R loss in armature, watts,	860
Per cent I^2R loss of output,	1.72

- ARMATURE TEMPERATURE RISE -

Peripheral velocity of revolving part,	5540
Radiating surface, Periph. core surface,	382
" " Conductor end connections,	2160
" " External surface of arm.,	630
" " Ventilating ducts and ends,	2552

Total radiating surface,	12692
Average watts radiated per sq.in. per degree,	.0054
Armature I^2R loss at full load, total,	860
Armature core loss at full load,	1142
Temperature rise of armature by thermometer,	23.50°C.
" " " " " resistance,	29.40 "

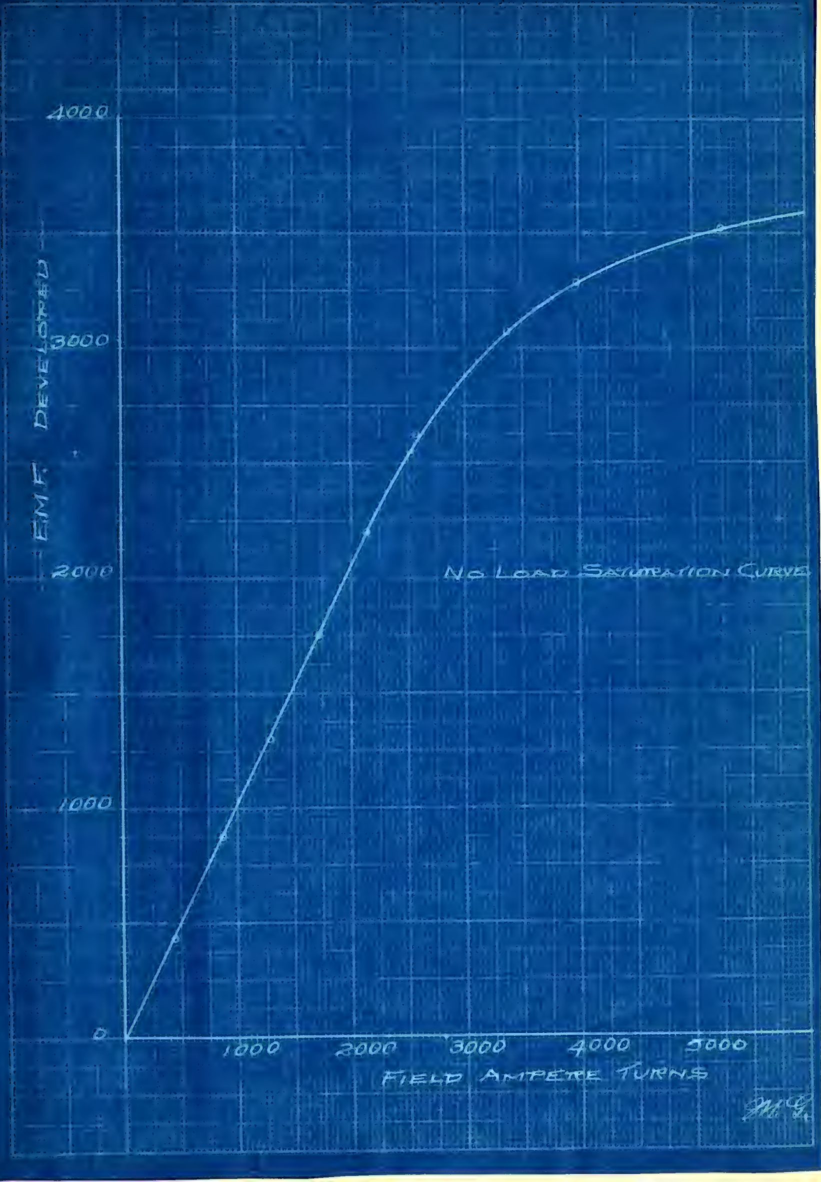
See accompanying saturation curve on coordinate paper.

- ARMATURE INDUCTANCE -

No. of adjacent slots per phase,	2
Slot inductance, covered, per group,	.01098
Average slot inductance, per group,	.00765
Slot inductance, uncovered, per group,	.004325
Total average field inductance per circuit,	.0596
Total inductance per circuit,	.1055
Armature reactance, per circuit, ohms,	39.4
Armature voltage reactance,	455
Angle of lag, ϕ,	9° 10'

- REGULATION -

Armature turns per phase,	330
Maximum current per phase,	12.56
Sin ϕ,	.27
Demagnetizing armature ampere turns per pole per phase,	15.3
Total demagnetizing armature turns per three phases,	275


No Load Saturation Curve
E.M.F. Developed
4000
3000
2000
1000
0
1000
2000
3000
4000
5000
Field Ampere Turns
M.G.

Effective flux at no load, per pole, maxwells,	1.5×10^6
% regulation, three phases loaded,	13

- FIELD WINDING -

Field ampere turns necessary, no load,	2300
Armature demegnetizing ampere turns, full load,	275
Total field ampere turns at full load,	2575
Length of winding space,	4
Depth of winding space, average,	1
Radiating area of one field coil,	100 sq.in.
Allowable rise in temperature of field coil at full load, °C,	36.5
e.m.f. impressed in fields,	59.4
Drop in field rheostat at full load,	60.6
Drop in each field coil, full load,	9.9
Allowable current in fields, full load,	10
No. of field turns,	257.5
Allowable circ. mils per ampere,	650
Cross sectional area of field conductors	6500c.m.
Wire gauge,	12
Mean length of one turn,	25"
Resistance of one field coil, 60°C,	.99
Field I^2R loss per coil,	99
Total field I^2R loss,	594

- EFFICIENCIES -

Armature I^2R loss, full load,	860
Armature core loss, " "	1142
Field I^2R loss, full load,	594
Output at full load,	50,000
Electrical efficiency, full load,	94.2 %

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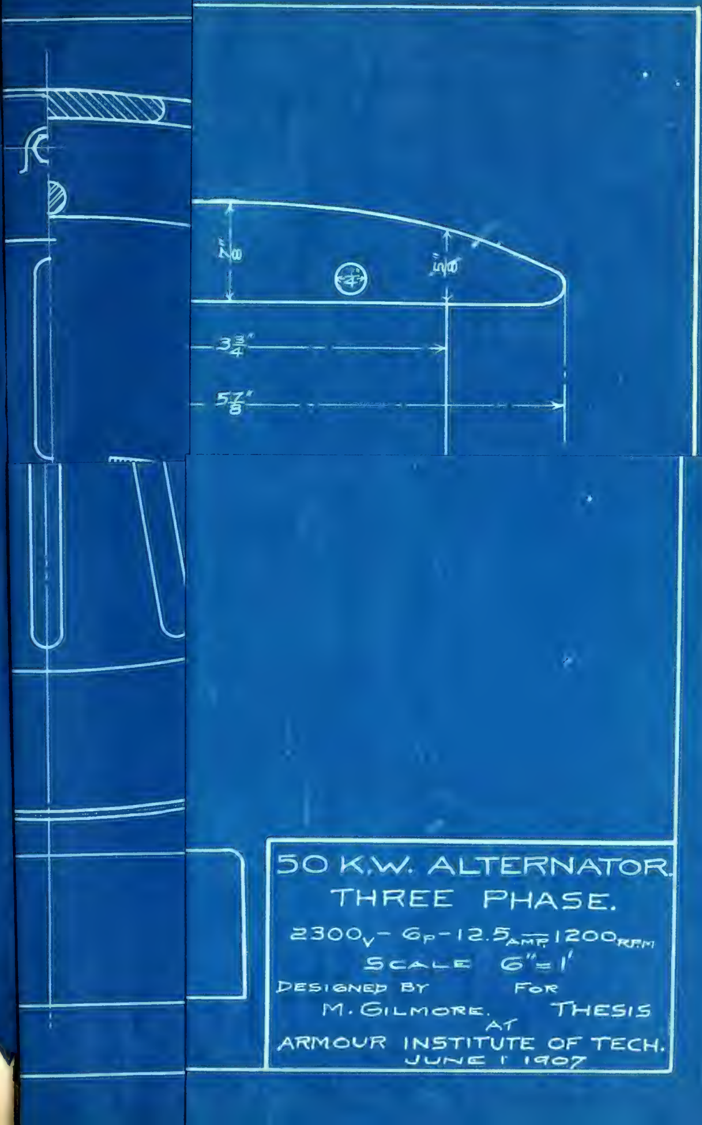
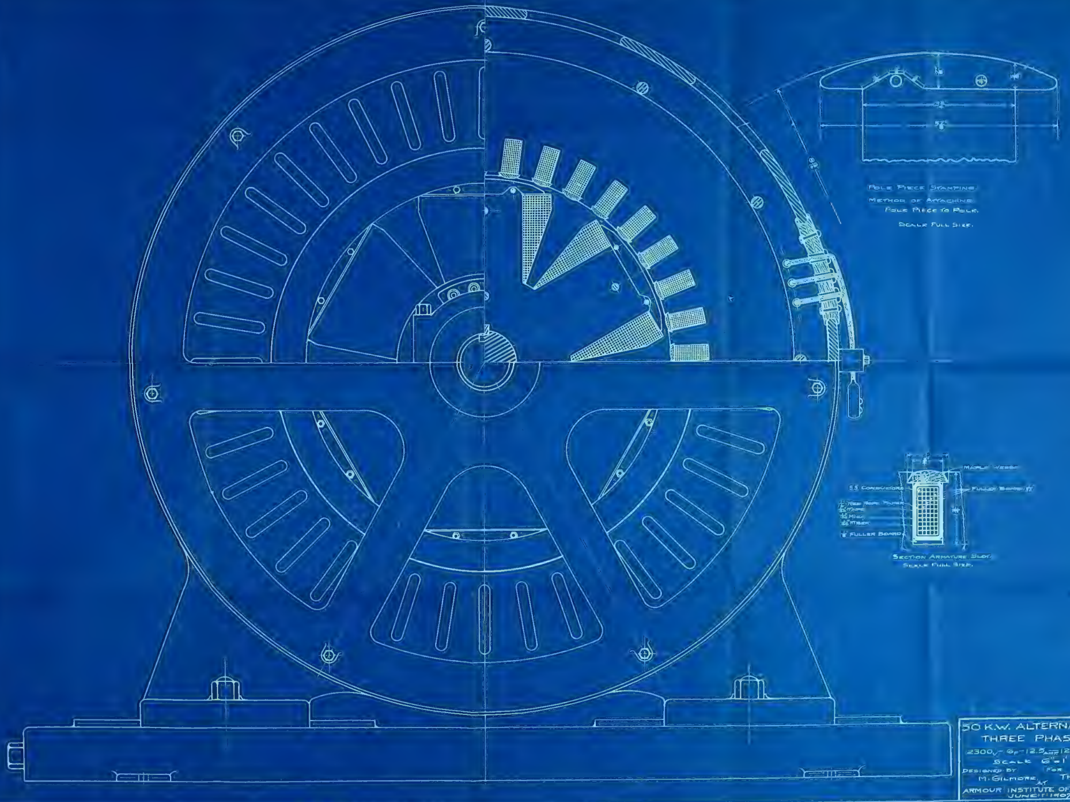


50 K.W. ALTERNATOR.
THREE PHASE.

2300$_{V}$ - 6$_{P}$ - 12.5$_{AMP.}$ 1200$_{R.P.M.}$

SCALE 6" = 1'

DESIGNED BY M. GILMORE.
FOR THESIS
AT
ARMOUR INSTITUTE OF TECH.
JUNE 1 1907



POLE PIECE STAMPING.
METHOD OF ATTACHING
POLE PIECE TO POLE.
SCALE FULL SIZE.

SECTION ARMATURE SLOT.
SCALE FULL SIZE.

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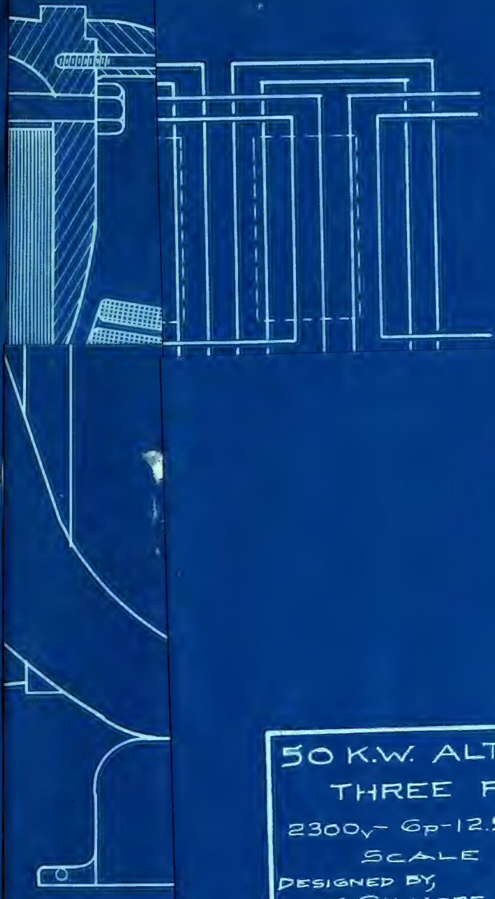

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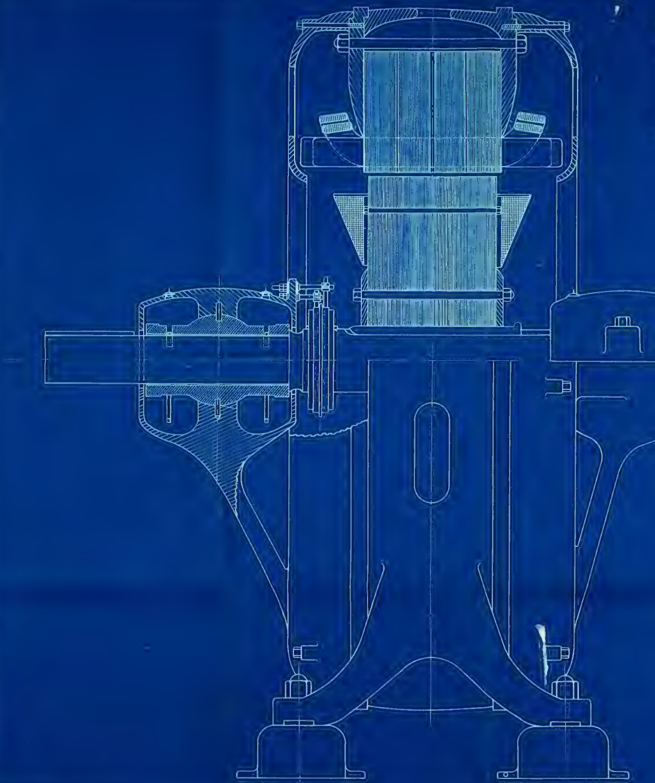

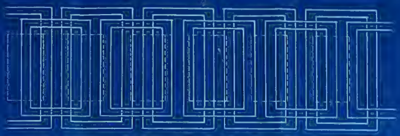

ARRANGMENT OF ARMATURE COILS.

50 K.W. ALTERNATOR.

THREE PHASE.

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